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Building Student Persistence with the use of Real-Time Feedback on Design Problems

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Building Student Persistence with the use of Real-Time Feedback on Design Problems

Abstract

Background: This paper examines the use of a real-time feedback document to assist students in navigating design problems. The design problems are multi-step challenges that culminate in design specifications for a small system. Each problem can be solved using a predictable sequence of calculations. Students customize their specific problem by inserting their own performance parameters to develop a solution that is unique for each student.

Purpose: Two challenges associated with design problems are those of providing effective feedback to students and of grading final submissions that are unique to each student. The research described proposes the use of a structured Excel spreadsheet to allow students to enter unique numbers for their design project and receive real-time feedback to track the progress of their solution. Literature suggests that the proper implementation of real-time feedback serves to increase student learning and motivation. The focus of this paper is the deployment and verification of the use of a real-time feedback tool to allow students to check their individual numerical values as they proceed through a given design problem.

Design Method: Students are provided with a structured Excel spreadsheet with each design problem. The cover sheet of the file allows students to enter their specific performance parameters and check calculated design values based on their chosen performance criteria. Secure background sheets compare student values to expected solutions and indicate if the students' solution values are within a specified tolerance (usually 1%) of the expected value. The spreadsheet provides a number of checkpoints along the way to the final solution to avoid the risk of carrying faulty numbers through the problem. The method is validated by results of student surveys to measure student persistence and engagement.

Results: Student surveys indicate that students find the spreadsheets provide valuable feedback and increase their persistence in solving the given design problems. From a faculty perspective, the increased effort by the students and the active feedback results in a simplified grading process. Both the prompt feedback and the structure of the feedback document are important. The design of the feedback document is critical in that it needs to provide sufficient feedback to keep the student on track, while also leaving enough gaps in the process to force the student to self-generate portions of the solution process.

Conclusions: Overall, the feedback documents allow the students to achieve a higher level of success by providing the necessary incentives to ensure their solution is proceeding along a correct path.

Keywords: Student assessment, Excel supported assignments.

Introduction

Typical engineering courses revolve around assessments that include homework problems, project work, exams, and laboratory reports. One particular challenge of all of these assessment methods is that of providing prompt and meaningful feedback to the students. This is a

multidimensional challenge. For example, an instructor can closely examine every jot and tittle in the work of a student, correcting sign errors, math errors, conceptual errors and other such details to provide comprehensive feedback. Such feedback, however, is not meaningful if the student merely glances at the grade at the top of the paper and then tosses the work aside. Detailed feedback also takes time, which separates the feedback from the learning. On the other hand, more prompt feedback (for example, returning papers in the class period following their submission) either requires the instructor to focus their time exclusively on grading for a day or two, or to reduce feedback to minimal levels. None of these scenarios, though common, provides much sense of satisfaction for either the instructor or the student.

Research demonstrates that prompt feedback is important. A number of texts, including Ambrose et al (2010), Fink (2013) and Nilson & Goodson (2017) cite prompt feedback in their lists of principles for effective learning. And while the feedback must be prompt, the student also needs to have time to attempt and fail (or succeed) before responding to the feedback (Brown et al., 2014). McTighe & O'Connor (2005) provide criteria for feedback that includes the need for it to be timely, specific, understandable, and allow the student a chance to act on the feedback. Shute (2008) adds criteria that formative feedback also be nonevaluative and supportive. These criteria are satisfied if the feedback enables the student to use the feedback to continue the learning process. Automated feedback, such as computer tutors, have been demonstrated to allow students to achieve proficiency in a topic in as little as 1/3 the time of traditional instruction methods (Anderson et al., 1995).

While the above ideas on effective feedback apply to all disciplines, the implementation of the ideas vary from one subject area to another. This paper examines the use of a feedback method designed specifically for small to medium scale engineering projects. The projects are design style problems where the emphasis is on applying course principles to evaluate the behavior of a system. Students are given the freedom to specify system parameters (within specified bounds), and then conduct an analysis of their system. Feedback is provided in the form of a structured Excel spreadsheet provided to students. The spreadsheet is a “fill-in-the-blank” sheet where students fill in a successive set of values as they proceed through the problem solution. The spreadsheet indicates if the values are right or wrong. This instant feedback motivates and encourages the student in their solution process by enabling the student to search for and correct errors as they progress through the problem solution.

The following sections present the feedback method in detail. The first section describes the typical problem scope and setup. The next section details various considerations in the setup of the spreadsheet to provide an appropriate level of feedback. A final section examines response to the spreadsheet feedback system.

Problem Setup

Design problems form one of the mainstays of engineering education. A particular challenge of assigning such problems to students is the ability to provide effective and efficient feedback. A true design problem allows each student to develop a unique solution. This, unfortunately, complicates the feedback process because each student is generating different numerical results. In this section, we examine the methods used to create a problem setup amenable to both individual solutions and real-time feedback.

The design problems used for the real-time feedback implementation are “dimensional” design problems. The system configuration is provided to the students and the students’ job is to specify and define dimensional parameters for the system. This form of problem allows the students sufficient freedom to create their own design, while at the same time providing a somewhat controlled problem where feedback is easily automated.

Two sample problems are provided in the appendix. One is from a Statics course ([Appendix 1](#)) and the second one is from a Machine Design course ([Appendix 2](#)). In each case, the student has the freedom to make design decisions that dictate the remainder of the solution process. Two essential elements of each problem are:

- 1) Student has the opportunity to specify personalized design values.
- 2) The solution process has a predictable flow.

The second of the above items is critical to allow for the use of real-time feedback. The next section describes the setup and implementation of the feedback system for the design problems.

Feedback Implementation

The real time feedback is provided through an Excel file given to the students. The file allows students to enter and check values as they proceed through their problem solution. This section presents information on the setup and formatting of the spreadsheet.

The file provided to students contains two sections. The first section is the cover sheet. The cover sheet shown in Fig. 1 applies to the design problem presented in Appendix A. The cover sheet is the only sheet to which the student has access. All boxes on the spreadsheet are locked, with the exception of those in yellow. The yellow boxes that stand by themselves (not attached to a red or green box) in Fig. 1 are “design boxes”. These are the boxes where students enter the design values that will make their solution a unique design.

The remaining yellow boxes are “solution check” boxes. Each of these is attached to an “indicator” box to indicate if the student has a correct value for that particular solution step. A green box with a visible number “1” indicates that a correct solution has been entered in the solution box, while an incorrect number produces a red box with a “0” visible.¹

A particular challenge of creating the student check sheet is determining which values to include as part of the check. The objective is to include values that are appropriately spaced in the solution process to provide the student with enough checkpoints to make them persist in the solution, but not so many that every calculation is laid out for them. In our check sheets, we try to include major results. Major results are typically based on a short series (2-4) of smaller calculations. As an example, to go from the “Dimension S” box to the “Pin Forces” box in Fig. 1, the student will need to write and solve three equilibrium equations. Even with the check boxes, the student still needs to figure out the process to move from one checkpoint to the next.

¹ Green and red seem like natural colors for “go” and “stop”, but the numbers are also required for the benefit of students who may have red-green color blindness.

Name:			
	Fill in the values requested. The coordinate (0,0) is at point D. Only enter values in boxes highlighted in yellow.		
	Part 1 - Pulley Specs		
		x of truss pulley	y of truss pulley
	Coordinates of pulley attached to truss	103.5	34.2
		x of lift pulley	y of lift pulley
	Coordinates of lift pulley at point B	80	100
	Number of ropes between pulleys	4	
	Tension in rope	19.9	1
	Part 2 - Frame Design		
	Dimension L1 (enter positive number)	28	
	Dimension H	50	
	Dimension L2	100.1	1
	Dimension S	33.1	1
	Magnitude of pin forces (lbs):		
	Pin B	81	0
	Pin C	329.3	1
	Pin D	247.3	1
	Pin E	278	0

Figure 1: Sample Student Spreadsheet

The second part of the spreadsheet provided to the students is a “background” sheet where calculations are performed. Figure 2 shows the background sheet corresponding to the student spreadsheet from Fig. 1. The background sheet has the following characteristics:

- 1) The sheet is hidden from student view.
- 2) The sheet is locked so students cannot use or edit the sheet.
- 3) The font on the sheet is set to “white” so the students cannot see the entries.

The background spreadsheet has two parts. The left side is the check side. The shaded boxes on the left side populate from the values entered by the student on the cover page. Alongside these boxes is a “percent difference” comparison between the student solution and the check sheet solution. Next to this is a “compare” column, which shows a binary value of 1 for a solution within tolerance (we commonly use a 1% tolerance), or outside of tolerance. The student page copies the values of “1” and “0” to drive the green and red comparison boxes.

[illegible]

Figure 2: Sample Background Sheet

The right side of the background sheet shown in Fig. 2 contains the calculations. One obvious limitation in the development of the check sheet is that calculations are limited to the capabilities of Excel. Fortunately, Excel provides adequate computational power to solve a variety of engineering design problems.

The check sheets are relatively easy to set up and they provide students with an intuitive method to test their solution process. The real question, however, is whether the check sheets impact student performance. The next section examines this question.

Student Response

The system described in the previous section provides students with an automated resource for obtaining real-time feedback on structured design problems. This section focuses on student response to the design problems and the automated feedback.

The feedback-based design assignments have been implemented in two different courses. One is a combined Statics/Dynamics course (sophomore level) and the other is a Machine Design course (junior level). Students in both courses ranked the projects among the most important of the course assessment methods. Table 1 shows survey results comparing the relative importance of various assessments as they relate to students' perception of their learning. The Excel supported spreadsheets stand out as the only assessment with all rankings at either the "Important" or "Very Important" levels. Other highly ranked assessments include a variation of the Excel supported design problems (supported by Finite Element Analysis for problems too complex for Excel support) and a series of team exercises. The highly ranked Team exercises represent another form of real-time feedback assignment that will be discussed in a future paper.

Table 1: Student Rankings of Course Assignments (Machine Design Course)

Assignment Type	Ranking					Ranking Average
	1 = Very Unimportant	2 = Unimportant	3 = Neutral	4 = Important	5 = Very Important	
Homework			8	13	11	4.09
Preclass problems			5	14	13	4.25
FEA tutorials		1	5	8	18	4.34
Individual Design problems with FEA verification		1	1	12	18	4.47
Individual Design problems with Excel verification				17	15	4.47
Team Exercises			1	11	20	4.59

Additional student responses were gathered to determine how the availability of the Excel sheets affected student engagement with the design problems. Table 2 summarizes responses to survey questions related to the usefulness of the feedback, and the effect of feedback on student persistence. The results from this survey indicate that the students used the feedback to guide and improve their solution, while also increasing their persistence in doing so.

Table 2: Impact of Excel Feedback on Student Engagement and Persistence.

Assignment Type	Ranking					Ranking Average
	1 = Strongly Disagree	2 = Disagree	3 = Neutral	4 = Agree	5 = Strongly Agree	
Automated check sheets provided useful feedback		2	2	20	45	4.57
The Excel spreadsheets helped me persist in finding a suitable solution to the problems presented		2	5	21	40	4.46

The spreadsheets also provide a grading benefit to both the students and the faculty. In a sense, the Excel sheets transfer the grading responsibility from the instructor to the student. The real-time feedback provided by the spreadsheet reveals errors as they happen. This gives the student a chance to pause, analyze, and correct the solution process. In essence, students grade their own work. The final project submission contains the spreadsheet with the student's calculations attached. Because the problem has been "pregraded", the instructor only needs to verify the calculation process of the attached student work.

Conclusions

The Excel supported design projects provide a basic scaffolding to assist students in the solution of design problems. The built-in feedback makes the students more persistent in their solution. The effectiveness of the Excel spreadsheet feedback stems from several sources. These include real-time feedback during the solution process, and the rough solution guide formed by the spreadsheet.

As with any teaching tool, the bottom line for effectiveness is the degree to which the tool supports learning. The Excel supported design projects make use of the following effective learning techniques:

- Real-time feedback – Encourages students to "self-grade" their problems – finding and correcting errors as they happen.
- Motivation – The ability to move through a problem step-by-step provides encouragement that the student is making positive progress toward the correct solution.
- Scaffolding – The spreadsheets are used in sophomore/junior level courses where students are having first encounters with multifaceted design problems. The checkpoints on the Excel sheet help the students to get past the "brain freeze" that can hinder the student from making an effective start on a problem solution.

One possible negative aspect of the spreadsheet support is the possibility that students will focus on the spreadsheet rather than the design problem. This can happen when the student tries to guess random solutions for the blanks or when the student tries to "hack" the spreadsheet background calculations. In the rare case that a student does successfully guess a correct value, they often assume they have correctly solved the problem step and tend to ignore the need to provide supporting calculations (which ultimately results in the solution being graded as incorrect). Similar results can happen if a student succeeds in hacking the background sheet where the solution process is somewhat cryptic² and difficult for the student to reproduce.

The spreadsheet supported design problems have received strongly positive responses from students. The built-in feedback also simplifies the ability of the instructor to assign design problems with unique solutions. The result is an enhanced student learning process.

² In spite of the protections applied to the background sheet, a need still exists to make the background calculations difficult for the student to reproduce. One important caution is the note that an Excel spreadsheet that is opened in Google Sheets removes all password protections on the sheet. This has not yet created obvious problems, but does require some extra precaution in creating the background sheet.

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Appendix 1 – Sample Design Problem for a Statics Course

(return to body of paper)

The construction industry provides a source for a variety of static analysis problems. This becomes even more evident when you have to rely on your wits rather than brute force to build something.

In this problem, we will examine the challenge of lifting a truss using your smarts and own strength rather than hiring a crane (\$1000/day) to do the work.

The truss and setup that we will be working with is shown in Fig. 1 below (all dimensions are in inches). The truss itself weighs 150 lbs. Our task is to design a frame crane that can attach to a supporting post to raise the truss into place. We will assume that there is a frame crane on each side of the truss. We will be dealing with the crane used to raise left side of the truss (and the crane on the right side will be identical).

As we set up this problem, we will be working with the following assumptions:

- The truss is being lifted at point A (coordinates (103.5, 34.2)).
- The pulley at the end of the frame, point B, must lie within the box shown. This box is defined by the coordinates: $0 < x < 80$; $50 < y < 100$
- The pull rope will be pulled in a direction that is parallel to frame member BCD.
- A pulley system between A and B will be used to reduce the force required to lift the truss.
- The pulley system carries a vertical load of half the weight of the truss. The horizontal load depends on the angle of the rope system.

Your task for this problem will consist of the following:

- 1) Design an appropriate pulley system to lift the truss.
- 2) Design the frame system to support your pulley, B.

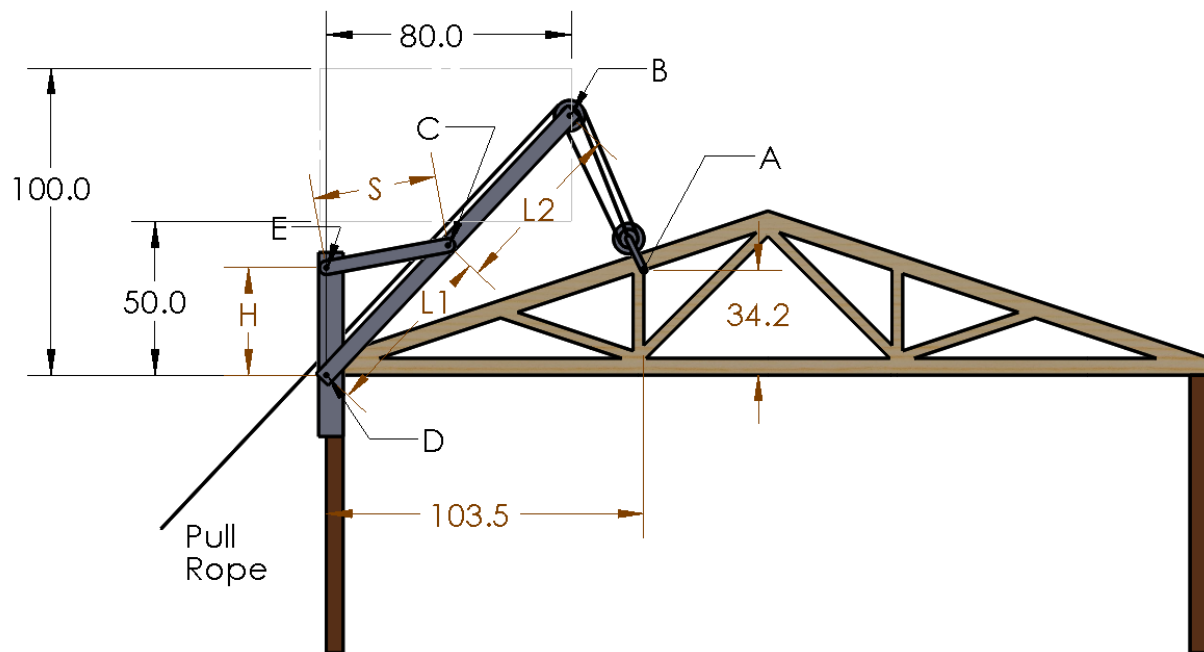


Figure 1: Truss and crane configuration.

Part 1 (10 pts): Define your pulley system. For this design, your target load in the pull rope is a force less than 25 lbs. To complete this part of the problem, do the following:

- a) Specify the location of pulley B.
- b) Determine how many ropes are necessary in your pulley system (the system in Fig 1 shows 3 ropes between A and B, you will need more than this).
- c) Draw a sketch that shows how your ropes attach to the pulley system. This is part of your cover sheet requirements.
- d) Calculate the force in the pull rope.

Part 2 (10 pts) Design your frame. Specify your frame dimensions, S, H, L1, and L2. The coordinate of point D is (0,0) and must be included as one ground support for your frame design. This requires you to specify the dimensions for S, H, and L1 (L2 is then determined by subtracting L1 from the distance DB). For this part of the project, use your design configuration from Part 1 (pulley location of B, number of ropes, force in pull rope) and determine the total force that is applied to each of the joints in the frame.

Completion of part 2 of the project includes the following:

- a) Specify lengths for H, and L1 (and correctly calculate the lengths for S and L2).
- b) Create a free-body diagram that properly shows the loading on frame member BCD. If a force at a joint on the member has an unknown direction, express that force with x and y force components. If a force at a joint has a known direction, express the force with a single vector with the correct direction orientation.
- c) Determine the total force at each joint.

To Submit:

- 1) Complete the Excel check sheet with your calculated numbers – submit this to the D2L dropbox.
- 2) Complete the attached cover sheet. Submit this in class with your calculations attached to the cover sheet.

Appendix 2 – Sample Design Problem for a Machine Design Course ([return to main paper](#))

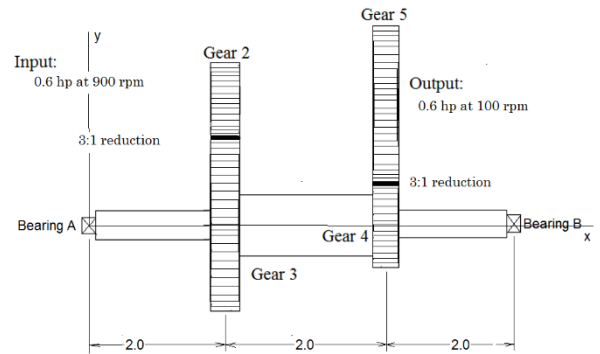
Machine Design – Individual Project 4 – Gear-Shaft-Bearing Design

This assignment consists of 3 problems. The problems are sequential and must be solved in order. All problems are to be solved on an individual basis. Students who submit duplicated work on any part of this assignment will automatically receive a grade of zero.

Problem 1: (5 pts) A gear train is to be developed to transmit 1.5 hp.

The gear set has a total 9:1 gear reduction taking place through two 3:1 gear steps as shown. The input pinion 2 rotates at a speed of 900 rpm while the output gear 5 rotates at a speed of 100 rpm. The expected lifetime operation of the assembly is 5,000 hours at the above speeds. Gears 2 and 5 both rotate in a CCW direction when viewed from the right. For this problem, do the following:

- Select an appropriate Boston Gear set from the choices listed on the Excel check sheet for your design. Select the smallest gear set that will work for this design. Note that all gear sets listed do not necessarily work for this design, but there are multiple choices that will work. The gear set must be able to **transmit 3.0 hp** (double the requirement to allow for a margin of safety). To simplify manufacturing and inventory, pinions 2 and 4 will be identical, as will gears 3 and 5.
- Specify your selection by filling in the appropriate boxes on the Excel check sheet. Note that several equally valid solution options exist for this problem (hopefully they are all accounted for in the check sheet!)
- Calculate the proper contact forces and torques for this problem. Fill in the values on the Excel check sheet for the forces of gear 2 applied to gear 3; and gear 5 applied to gear 4.



Problem 2: (5 pts) Continuing with the same gear set from problem 1.

- Solve for the reaction forces at the bearings and fill these in on the check sheet.
- Determine the torque that is transmitted through the shaft between gears 3 and 4.
- Use the Boston Gear catalog to select appropriate 1600 series bearings for the shaft. The bearings will fit on a step that is smaller than the gear diameter of the shaft. (i.e. the ID of the bearings must be smaller than the ID of the gears selected from problem 1). Use identical bearings on each side.

Problem 3: (10 pts) Continuing with the problem, do the following:

- To calculate this part, be sure your shaft sizes match your selected gears. Make the large step between the gears approximately 1.2 times the diameter of the next largest diameter on the shaft. Use a radius of 0.12 at all steps.
- Once you have the shaft properly sized, determine the worst case load point. Determine the total moment and torque at this point. Determine any stress concentrations that may exist at this point.
- Using this load and stress concentration information, verify that the shaft size is large enough for the loads. Use 1040 cold rolled steel as the shaft material with $S_y = 71\text{ksi}$ and $S_{UT} = 85\text{ ksi}$. Assume 50% reliability.